

DESCRIPTION

EXHAUST PURIFYING APPARATUS AND EXHAUST PURIFYING METHOD
FOR INTERNAL COMBUSTION ENGINE5
TECHNICAL FIELD

10 The present invention relates to an exhaust purifying apparatus and an exhaust purifying method for an internal combustion engine.

BACKGROUND ART

15 As disclosed in Japanese Laid-Open Patent Publication No. 5-44434, a typical exhaust purifying apparatus applied to an internal combustion engine such as a vehicle diesel engine includes a PM filter that is located in the exhaust system. The PM filter traps particulate matter, which is predominantly composed of soot in exhaust gas.

20 In an internal combustion engine provided with such an exhaust purifying apparatus, PM elimination control is performed to prevent the PM filter from being clogged with particulate matter (PM) when the accumulation amount of particulate matter in the PM filter estimated from, for example, the operating condition of the engine is more than or equal to a permissible value. In the PM elimination control, fuel is added to exhaust gas in a section upstream of the PM filter so that oxidation of unburned fuel component on the catalyst of the PM filter generates heat to increase the temperature of the catalyst. Accordingly, particulate matter on the PM filter is burned. When it is determined that particulate matter deposited on the PM filter is completely burned, the estimated accumulation amount of particulate matter on the PM filter is set to zero, and the PM elimination

25
30
35

control is completed.

The PM elimination control is sometimes suspended due to stopping of the engine during the execution. When the engine is started again and execution of the PM elimination control becomes possible, the PM elimination control is not resumed if the accumulation amount of particulate matter at the time of suspension is less than the permissible value. However, if incomplete execution of the PM elimination control due to suspension is repeated several times, the following drawbacks are likely to occur in relation to the estimated accumulation amount of particulate matter.

The estimated accumulation amount of particulate matter may contain an error in relation to the actual accumulation amount. Such an error is eliminated by setting the estimated amount of particulate matter to zero when the PM elimination control is completed so that particulate matter deposited on the PM filter is completely burned. However, after execution and suspension of the PM elimination control are repeated a few times, accumulation of particulate matter on the PM filter in normal operation of the engine and burning of the particulate matter in the PM elimination control up to its suspension are repeated without the estimated particulate matter accumulation amount being set to zero. While the accumulation amount of particulate matter is repeatedly increased and reduced, the estimated accumulation amount can be greatly deviated from the actual accumulation amount.

When the estimated accumulation amount of particulate matter is significantly less than the actual accumulation amount, execution of control for richening the exhaust air-fuel ratio based on the estimated accumulation amount of particulate matter can excessively increase the catalyst bed temperature of the PM filter. Such an excessive catalyst bed

temperature is caused in the following manner. When unburned fuel component is supplied to the PM filter based on the control for richening the exhaust air-fuel ratio, oxidation of the unburned fuel component causes particulate matter

5 deposited on the PM filter to burn. At this time, a greater amount of particulate matter than estimated has been accumulated, and the heat generated when the particulate matter is burned is increased accordingly.

10 SUMMARY OF THE INVENTION

Accordingly, it is an objective of the present invention to provide an exhaust purifying apparatus of an internal combustion engine that prevents an estimated accumulation
15 amount of particulate matter about a catalyst from being significantly deviated from the actual accumulation amount due to suspension of PM elimination control. The present invention further provides an exhaust purifying method.

20 To achieve the foregoing and other objectives and in accordance with the purpose of the present invention, the invention provides an exhaust purifying apparatus for an internal combustion engine. The apparatus estimates an accumulation amount of particulate matter trapped about a
25 catalyst in an exhaust system. When the estimated accumulation amount is equal to or more than a permissible value, the apparatus executes PM elimination control for supplying unburned fuel component to the catalyst to increase the temperature of the catalyst and burning the trapped
30 particulate matter. The apparatus sets the estimated accumulation amount to zero at the completion of the PM elimination control. When execution of the PM elimination control becomes possible after suspension of the control, the apparatus resumes the PM elimination control even if the
35 accumulation amount of particulate matter about the catalyst

is less than the permissible value.

The present invention further provides an exhaust purifying method for an internal combustion engine. The method includes estimating an accumulation amount of particulate matter trapped about a catalyst in an exhaust system of the internal combustion engine. The method further includes executing PM elimination control when the estimated accumulation amount is equal to or more than a permissible value. In which control, unburned fuel component is supplied to the catalyst to increase the temperature of the catalyst and the trapped particulate matter is burned. The method further includes setting the estimated accumulation amount to zero at the completion of the PM elimination control. The method further includes resuming the PM elimination control when execution of the PM elimination control becomes possible after suspension of the control, even if the accumulation amount of particulate matter about the catalyst is less than the permissible value.

Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig.1 is a diagrammatic view illustrating the overall configuration of an internal combustion engine to which an exhaust purifying apparatus according to the present invention is applied;

Fig. 2 is a graph showing changes in combustion rate of unburned fuel (HC) and PM about a catalyst relative to changes in the catalyst bed temperature;

Figs. 3(a) and 3(b) are time charts illustrating changes in PM accumulation amount and catalyst bed temperature during PM elimination control;

Fig. 4 is a graph showing the relationship between a PM accumulation amount (determination value) D_c and holding period t_2 ;

Fig. 5 is a graph showing the relationship between a PM accumulation amount (determination value) D_b and holding period t_3 ;

Figs. 6(a) and 6(b) are time charts illustrating the manner of adding fuel and changes in the exhaust air-fuel ratio due to the fuel addition during burn-up control;

Figs. 7(a) and 7(b) are time charts illustrating changes in the PM accumulation amount and the catalyst bed temperature when the PM elimination control is executed and completed with the estimated PM accumulation amount being deviated from the actual accumulation amount;

Figs. 8(a) and 8(b) are time charts illustrating changes in the PM accumulation amount and the catalyst bed temperature when the PM elimination control is repeatedly executed and suspended;

Figs. 9(a) and 9(b) are time charts illustrating changes in the PM accumulation amount and the catalyst bed temperature when the PM elimination control is first suspended and then resumed and completed; and

Fig. 10 is a flowchart showing the procedure for resuming the PM elimination control.

BEST MODE FOR CARRYING OUT THE INVENTION

An exhaust purifying apparatus for an internal combustion engine according to a preferred embodiment of the present

invention will now be described with reference to Figs. 1 to 10(d).

Fig. 1 illustrates the configuration of an internal combustion engine 10 to which the exhaust purifying apparatus according to this embodiment is applied. The internal combustion engine 10 is a diesel engine that includes a common rail fuel injection device, and a turbocharger 11. The engine 10 includes an intake passage 12, combustion chambers 13, and an exhaust passage 14.

The intake passage 12 forms an intake system for the internal combustion engine 10. In the most upstream section of the intake passage 12, an air cleaner 15 is located. From the air cleaner 15 toward the downstream side, the air flow meter 16, a compressor 17 incorporated in the turbocharger 11, an intercooler 18, and an intake throttle valve 19 are provided in the intake passage 12. The intake passage 12 is branched at an intake manifold 20 located downstream of the intake throttle valve 19, and connected to each of the combustion chambers 13 of the internal combustion engine 10 through intake ports 21.

In the exhaust passage 14, which forms part of the exhaust system for the internal combustion engine 10, an exhaust port 22 is connected to each combustion chamber 13. The exhaust ports 22 are connected to an exhaust turbine 24 of the turbocharger 11 through an exhaust manifold 23. In a section of the exhaust passage 14 that is downstream of the exhaust turbine 24, a NOx catalytic converter 25, a PM filter 26, and an oxidation catalytic converter 27 are provided in this order from the upstream side.

The NOx catalytic converter 25 supports an occlusion-reduction NOx catalyst. The NOx catalyst occludes NOx in

exhaust gas when the concentration of oxygen in exhaust gas is high, and emits the occluded NOx when the concentration of oxygen in the exhaust gas is low. If a sufficient amount of unburned fuel component, which functions as a reducing agent, exists in the vicinity thereof, the NOx catalyst reduces emitted NOx to purify the exhaust gas.

The PM filter 26 is made of a porous material and traps particulate matter (PM), which is predominantly composed of soot, in exhaust. Like the NOx catalytic converter 25, the PM filter 26 supports an occlusion-reduction NOx catalyst. The NOx catalyst of the PM filter 26 reduces emitted NOx to purify the exhaust gas. The reaction triggered by the NOx catalyst burns (oxidizes) and removes the trapped PM.

The oxidation catalytic converter 27 supports an oxidation catalyst. The oxidation catalyst oxidizes hydrocarbon (HC) and carbon monoxide (CO) in exhaust gas to purify the exhaust gas.

In sections upstream of and downstream of the PM filter 26, an input gas temperature sensor 28 and an output gas temperature sensor 29 are provided, respectively. The input gas temperature sensor 28 detects an input gas temperature, which is the temperature of exhaust gas that flows into the PM filter 26. The output gas temperature sensor 29 detects an output gas temperature, which is the temperature of exhaust gas that has passed through the PM filter 26. Also, a differential pressure sensor 30 is provided in the exhaust passage 14. The differential pressure sensor 30 detects a pressure difference between a section upstream and a section downstream of the PM filter 26. Oxygen sensors 31, 32 are located in a section of the exhaust passage 14 that is upstream of the NOx catalytic converter 25 and a section of the exhaust passage 14 between the PM filter 26 and the

oxidation catalytic converter 27, respectively. The oxygen sensors 31, 32 detect the concentration of oxygen in exhaust gas.

5 The internal combustion engine 10 further includes an exhaust gas recirculation device (EGR device) for returning some of the exhaust gas to the air in the intake passage 12. The EGR device includes an EGR passage 33 that connects the exhaust passage 14 with the intake passage 12. The most
10 upstream section of the EGR passage 33 is connected to a section of the exhaust passage 14 that is upstream of the exhaust turbine 24.

15 In the EGR passage 33, an EGR catalyst 34, an EGR cooler 35, and an EGR valve 36 are provided in this order from the upstream side. The EGR catalyst 34 reforms recirculated exhaust gas. The EGR cooler 35 cools the reformed exhaust gas. The EGR valve 36 adjusts the flow rate of the reformed and cooled exhaust gas. The most downstream section of the
20 EGR passage 33 is connected to a section of the intake passage 12 that is downstream of the intake throttle valve 19.

25 An injector 40 is provided in each combustion chamber 13 of the internal combustion engine 10 to inject fuel to be combusted in the combustion chamber 13. The injectors 40 are connected to a common rail 42 with a high-pressure fuel pipe 41. High-pressure fuel is supplied to the common rail 42 through a fuel pump 43. The pressure of high-pressure fuel in the common rail 42 is detected by a rail pressure sensor 44
30 attached to the common rail 42. The fuel pump 43 is capable of supplying low-pressure fuel to a fuel adding valve 46 through a low-pressure fuel pipe 45.

35 Various control procedures for the internal combustion engine 10 are executed by an electronic control device 50.

The electronic control device 50 includes a CPU that executes various computation processes related to control of the engine 10, a ROM storing programs and data necessary for the control, a RAM for temporarily storing the computation results of the CPU, and input and output ports for inputting and outputting signals from and to the outside.

In addition to the above described sensors, the input port of the electronic control device 50 is connected to an NE sensor 51 for detecting the rotational speed of the engine 10, an acceleration pedal sensor 52 for detecting the degree of depression of an acceleration pedal, and a throttle valve sensor 53 for detecting the opening degree of the intake throttle valve 19. The output port of the electronic control device 50 is connected to a drive circuit for driving the intake throttle valve 19, the EGR valve 36, the injector 40, the fuel pump 43, and the fuel adding valve 46.

Based on detected signals from the above described sensors, the electronic control device 50 grasps the operating condition of the engine 10. According to the grasped operating condition, the electronic control device 50 outputs command signals to the drive circuits of the devices connected to the output port. The electronic control device 50 executes various control procedures such as control of the opening degree of the intake throttle valve 19, EGR control based on the opening degree control of the EGR valve 36, control of the amount, the timing and the pressure of fuel injection from the injector 40, and control related to fuel addition by the fuel adding valve 46.

In this embodiment, to prevent the NOx catalytic converter 25 and the PM filter 26 from being clogged with PM, PM elimination control is performed, in which PM trapped by the NOx catalytic converter 25 and the PM filter 26 are burned

to purify exhaust gas. In the PM elimination control, unburned fuel component is supplied to the NOx catalytic converter 25 and the NOx catalyst of the PM filter 26 so that the unburned fuel component is oxidized in exhaust gas or on each catalyst to generate heat. Accordingly, the catalyst is heated to a temperature of about 600 to 700°C, and PM about the catalyst is burned.

During the PM elimination control, unburned fuel component may be supplied to the catalysts by sub-injection (after injection) in an exhaust stroke or an expansion stroke, which injection is executed after fuel is injected from the injector 40 to be combusted in the combustion chambers 13. Alternatively, unburned fuel may be supplied by adding fuel to exhaust gas from the fuel adding valve 46. To minimize extra fuel consumption due to the PM elimination control, the amount of unburned fuel component added to the catalysts in the PM elimination control is limited to the minimum value that allows for a necessary increase in the temperature of the catalysts.

In this embodiment, the PM elimination control is performed when the following requirements are all satisfied.

The elimination of PM is requested. A request for the PM elimination is made when clogging of the PM filter 26 is recognized based on the fact that the PM accumulation amount of the PM filter 26 estimated from the engine operating condition reaches and exceeds the highest value of a permissible range.

A detected value of the input gas temperature sensor 28 (input gas temperature th_{ci}) is more than or equal to a lower limit temperature A (for example, 150°C) for performing the PM elimination control. Also, the catalyst bed temperature of

the NOx catalyst, which is estimated from the history of the engine operating condition is more than or equal to a lower limit temperature B for performing the PM elimination control. The lower limit temperatures A, B are the lowest values of the exhaust temperature and the catalyst bed temperature that cause oxidation sufficient to increase the catalyst bed temperature as unburned fuel component is supplied.

The detected value of the input gas temperature sensor 28 is less than an upper limit value C in a temperature range for avoiding excessive temperature increase of the catalysts due to heat generated by the PM elimination control.

The detected value of the output gas temperature sensor 29 is less than an upper limit value D in a temperature range for avoiding excessive temperature increase of the catalysts due to the PM elimination control.

Fuel addition to exhaust gas is permitted. That is, the engine operating condition is in a range to permit the fuel addition to exhaust gas. The addition of fuel to exhaust gas is permitted in the internal combustion engine 10 as long as the engine 10 is not stalling, the cylinders have been distinguished, and the depression degree of the acceleration pedal is not limited.

The PM elimination control will now be described with reference to Fig. 2 to 6(b).

Fig. 2 is a graph showing changes in the combustion rates of unburned fuel (HC) and PM collected on the surface of the catalysts as the catalyst bed temperature increases at the NOx catalytic converter 25 and the PM filter 26. As obvious from Fig. 2, unburned fuel collected on the catalysts is burned at a relatively low catalyst bed temperature (about 300°C), and

PM collected on the catalysts is burned when the catalyst bed temperature is increased to a relatively high temperature, for example, in the range between 600 and 700°C, inclusive.

Therefore, if the catalyst bed temperature is suddenly

5 increased to a value of about 700°C, a great amount of unburned fuel and PM collected on the catalysts are burned, and the generated heat can excessively increase the catalyst bed temperature.

10 Such an excessive increase in the catalyst bed temperature is prevented by discretely increasing the catalyst bed temperature as shown in Fig. 3(b). That is, to burn unburned fuel (HC) and PM collected on the surface of the catalysts in stages, the catalyst bed temperature is increased
15 to 300, 600, 630, and 650°C, successively. Specifically, first the minimum amount of unburned fuel component required for increasing the catalyst bed temperature to 300°C is supplied to the catalysts. As the catalyst bed temperature is increased toward 300°C, unburned fuel collected on the
20 catalysts is burned. When the catalyst bed temperature reaches 300°C, the catalyst bed temperature is increased to 600°C and is held at this temperature for holding period t_2 . Then, the catalyst bed temperature is increased to 630°C and is held at this temperature for holding period t_3 . Finally,
25 the catalyst bed temperature is increased to 650°C.

As shown in Fig. 4, the holding period t_2 , during which the catalyst bed temperature is held at 600°C, is set shorter as the PM accumulation amount (determination value) D_c at time
30 T_c , where the catalyst bed temperature is switched from 300°C to 600°C, is reduced. As shown in Fig. 5, the holding period t_3 , during which the catalyst bed temperature is held at 630°C, is set shorter as the PM accumulation amount (determination value) D_b at time T_b , where the catalyst bed
35 temperature is switched from 600°C to 630°C, is reduced. The

holding periods t_2 and t_3 are varied according to the PM accumulation amounts D_c , D_b so that the time for the PM elimination control to burn PM is minimized, and deterioration of the fuel consumption due to the amount of fuel used in the control is minimized.

As the catalyst bed temperature is increased in stages in the above described PM elimination control, PM collected about the catalysts is burned, and the PM accumulation amount is reduced as shown in Fig. 3(a). However, at the upstream end of the NOx catalytic converter 25 and the upstream end of the PM filter 26, some PM remains even if the above described PM elimination control is performed. The reason why PM remains is believed to be that PM is likely to be deposited at the exhaust upstream end of the NOx catalytic converter 25 and the exhaust upstream end of the PM filter 26, and the supply of unburned fuel component in the PM elimination control cannot supply a sufficient amount of unburned fuel component per unit time to burn the PM completely. Particularly, in the NOx catalytic converter 25, which is located upstream of the PM filter 26, a greater amount of PM that is not burned in the PM elimination control remains at the upstream end.

Thus, at the final stage of the PM elimination control, that is when the PM accumulation amount is reduced to a determination value D_a close to zero (for example, 0.3 g), burn-up control is performed to burn PM that cannot be burned in the PM elimination control. The overview of the burn-up control will be described with reference to Figs. 6(a) and 6(b). Fig. 6(a) shows the manner in which the fuel adding valve 46 adds fuel, and Fig. 6(b) shows changes in the exhaust air-fuel ratio.

As shown in Fig. 6(a), concentrated intermittent fuel addition is repeatedly performed and stopped in the burn-up

control. The concentrated intermittent fuel addition increases the amount of unburned fuel component and oxygen supplied to the catalysts of the NOx catalytic converter 25 and the PM filter 26 to a level sufficient for burning the PM that cannot be burned in the PM elimination control.

Therefore, the concentrated intermittent fuel addition permits the PM to be burned.

The concentrated intermittent fuel addition unavoidably causes the catalyst bed temperature to increase noticeably. Thus, the fuel addition is periodically stopped, thereby suppressing excessive increase in the catalyst bed temperature. As a result, intermittent concentrated fuel addition is repeatedly performed and stopped, and the exhaust air-fuel ratio is repeatedly reversed between a rich state and a lean state as shown in Fig. 6(b). The burn-up control is ended when the repetitions of performing and stopping of the concentrated intermittent fuel addition has reached a number (in this embodiment, three times) that is sufficient for burning the PM remaining in the NOx catalytic converter 25 and the PM filter 26.

The PM elimination control is completed based on the end of the burn-up control. When the PM elimination control is completed, the PM accumulation amount about the catalysts estimated from the engine operating condition becomes zero. In other words, the PM accumulation amount is set to zero when the PM elimination control is completed.

The PM elimination control may be suspended during execution. For example, when the engine 10 is stopped, the PM elimination control is suspended even during the execution thereof. Also, the PM elimination control is suspended when deactivation of the catalyst occurs, in which the catalyst bed temperature is lowered even if unburned fuel component is

being supplied, due to a drop of the exhaust temperature.

Such deactivation of a catalyst is caused by a vicious circle in which a drop in the exhaust temperature during the PM elimination control deactivates a catalyst and temporarily hampers oxidation of unburned fuel, and the unburned fuel stays collected on the catalyst and decreases the surface area of the catalyst that is exposed to exhaust gas, and the degree of activation of the catalyst is lowered further, and so on. If unburned fuel component is supplied to each catalyst in the PM elimination control during deactivation of the catalyst, the unburned fuel component is emitted to the outside in an incomplete combustion state. Therefore, the exhaust emission can be deteriorated. For example, a great amount of smoke may be emitted. The PM elimination control is thus suspended when the catalyst is deactivated.

However, if incomplete execution of the PM elimination control due to suspension is repeated several times, the estimated PM accumulation amount is greatly deviated from the actual accumulation amount, which causes problems. The reason why repetitive execution and suspension of the PM elimination control causes the estimated PM accumulation amount to be deviated from the actual accumulation amount will be described with reference to Figs. 7(a) to 8(b).

Since the PM accumulation amount used in the PM elimination control is a value estimated from the engine operating condition, the PM accumulation amount can be deviated from the actual accumulation amount. For example, as shown in Fig. 7(a), the estimated PM accumulation amount (solid line L1) can be deviated from the actual accumulation amount (broken line L2). Normally, such an error is eliminated by setting the estimated PM accumulation to zero when PM collected about the catalyst is completely burned and

the PM elimination control is completed. That is, as shown in Fig. 7(b), when the PM elimination control that has been started at time T1, where the estimated PM accumulation amount reaches and exceeds a permissible value, is completed at time T2, the PM collected about each catalyst is completely burned, and the estimated PM accumulation amount is set to zero. This allows the estimated PM accumulation amount to correspond to the actual accumulation amount, and an error between these values is eliminated.

As described above, if the PM elimination control is completed, an error between the estimated PM accumulation amount and the actual accumulation amount is eliminated. However, if the PM elimination control is suspended before it is completed, such an error is not eliminated. For example, as shown in Fig. 8(a), when the PM elimination control is suspended at time T3 due to stopping of the engine 10 or deactivation of the catalysts, if the PM accumulation amount has dropped to a value less than the permissible value at the time of suspension, the PM elimination control will not be resumed even if the engine 10 is started again or the catalyst is activated so that the PM elimination control is possible. In this case, since the PM elimination control is not completed, setting the estimated PM accumulation amount to zero to eliminate the error is not performed. Then, when the PM accumulation amount reaches the permissible value again, the PM elimination control is executed (time T4).

If execution and suspension of the PM elimination control are repeated a few times (T4 to T7 in Fig. 8(b)), accumulation of PM about each catalyst in a normal operation of the engine 10 and burning of the PM in the PM elimination control are repeated without the PM accumulation amount being set to zero. As a result, the estimated PM accumulation amount is increased and decreased in a manner as shown in Fig. 8(a), during which

the estimated PM accumulation amount can be significantly deviated from the actual accumulation amount. When the estimated PM accumulation amount is significantly less than the actual accumulation amount, for example, when the actual accumulation amount is in a state indicated by broken line L3 relative to the estimated PM accumulation amount indicated by solid line L1 in Fig. 7(a), the following conditions occur at the final stage of the PM elimination control.

That is, the burn-up control, which should be started when the estimated PM accumulation amount (L1) is reduced to the determination value D_a (0.3g), is started in a state where the amount of PM about each catalyst is significantly greater (indicated by X in the Fig. 7(a)) than the determination value D_a . Then, when the unburned fuel component is supplied to each catalyst during the control, oxidation of the unburned fuel component causes PM to burn. However, since the actual amount of PM accumulation is more than the assumed value (0.3g), the heat of burning of the PM is great, which can excessively increase the catalyst bed temperature of the NOx catalytic converter 25 and the PM filter 26.

To avoid such a problem, when execution of the PM elimination control is possible after suspension of the control, the PM elimination control is resumed regardless of whether the PM accumulation amount is less than the permissible value. The resumed PM elimination control is executed until it is completed. Figs. 9(a) and 9(b) show an example of changes in the PM accumulation amount and the state of the PM elimination control in a case where the resumption of the PM elimination control is executed.

In Figs. 9(a) and 9(b), the execution of the PM elimination control becomes possible at time T8 after it is suspended. Then, even if the PM accumulation amount is less

than the permissible value, the PM elimination control is resumed and continued until it is completed at time T9. By completing the PM elimination control, PM accumulated about the catalysts is completely burned, and the estimated PM accumulation value is set to zero, which eliminates an error between the estimated PM accumulation amount and the actual accumulation amount. Therefore, the problems described above, which are caused by the error not being eliminated, are avoided.

The procedure for the resumption of the PM elimination control will now be described with reference to Fig. 10, which shows a control resumption routine. The control resumption routine is executed as an interrupt by the electronic control device 50, for example, at predetermined time intervals.

In the routine, whether the PM elimination control of the previous cycle was suspended is determined based on a history of the operating condition of the engine (S101). If the outcome is positive, whether the PM elimination control is executable is determined (S102). For example, whether the engine is running and the deactivation of the catalyst is eliminated is determined (S102). Whether the deactivation of the catalyst is eliminated is determined based on whether the catalyst bed temperature has a value that burns unburned fuel component collected on the catalysts (for example 300°C) or based on whether the catalyst bed temperature will soon have such a value because the engine load has been high for a predetermined period.

When the outcome of step S102 is positive, the PM elimination control is executed (S103) regardless of the current PM accumulation amount, and continued until it is completed. Even if the PM elimination control is suspended after it has been resumed according to step S103, the PM

elimination control will be continued until it is completed since the control is repeatedly resumed according to steps S101 to S103.

5 After being resumed, the PM elimination control discretely increases the catalyst bed temperature. The holding periods t_2 and t_3 for the catalyst bed temperatures of 600°C and 630°C are shortened as the PM accumulation amounts D_c and D_b are reduced. Also, at the final stage in the
10 resumed PM elimination control, the burn-up control is executed to completely burn PM accumulated about the catalysts.

15 The above-described embodiment has the following advantages.

(1) When the execution of the PM elimination control becomes possible after it has been suspended, the PM elimination control is resumed even if the current PM
20 accumulation amount is less than the permissible value. The resumed PM elimination control is continued until it is completed so that PM accumulated about the catalysts is completely burned. When the PM is completely burned and the PM elimination control is completed, the estimated PM
25 accumulation value is set to zero, which eliminates an error between the estimated PM accumulation amount and the actual accumulation amount. Therefore, repetitive execution and suspension of the PM elimination control without completion of the control are avoided. Accordingly, an error between the
30 estimated PM accumulation amount and the actual accumulation amount, which would be increased during the repetitive execution and suspension, is suppressed.

(2) When the PM elimination control is suspended, burning
35 of PM accumulated about each catalyst has progressed to a

certain degree. The less the remaining PM accumulation at the time of suspension, the shorter the time for execution of the PM elimination control after resumption can be set. That is, even a shorter period for execution will be sufficient to

5 completely burn PM accumulated about each catalyst.

Accordingly, in the resumed PM elimination control, the less the PM accumulation amounts D_c and D_b , the shorter the holding periods are set for t_2 and t_3 . Accordingly, the execution time of the control is shortened in accordance with a decrease
10 in the PM accumulation amount. Therefore, time required for completion of the control after resumption is shortened.

Also, degradation in the fuel consumption due to a uselessly extended period for the control is avoided.

15 (3) In the PM elimination control resumed after suspension, the burn-up control is executed at the final stage, so that PM accumulated about each catalyst is completely burned and the actual PM accumulation amount is reduced to zero. Therefore, when the PM elimination control
20 is completed after being resumed, a situation is avoided in which PM remains about each catalyst even if the estimated PM accumulation amount is set to zero and the estimated PM accumulation amount does not correspond to the actual accumulation amount.

25

The above-described embodiments may be modified as follows.

The execution period of the PM elimination control does
30 not need to be varied according to the PM accumulation amount, but may be fixed for a period that is sufficient for PM accumulated about each catalyst to be completely burned by the PM elimination control.

35 It may be configured so that the execution period is not

fixed in the PM elimination control that is resumed after suspension and is fixed in the PM elimination control that is completed without being suspended.